Atlantic from the European coast west to the 30th meridian, and the waters off the Tail of the Grand Banks where Labrador Current and Gulf Stream meet. One of the main objects which gives stimulus to the *Meteor* Expedition, now in the South Atlantic Ocean, is this "leveling" work of hydrographic engineering. We wish in closing to emphasize the fact that delineating the dynamic topography of the oceans, at least in their main features, is a new and promising field unfolding in physical oceanography.

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A STUDY OF THE NORTHERN PART OF THE LABRADOR CURRENT

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In the discussion of the Labrador Current which follows, the observation made last summer during the cruise of the schooner *Chance* will be used as a basis. A preliminary report of this trip will shortly appear in *Science*. During the cruise two profiles were run at right-angles to the general trend of the Labrador coast, one just south of Hamilton Inlet and the other off Nachvak Bay which is about sixty miles south of Cape Chidley, the northeastern extremity of the Labrador Peninsula. Besides these physical observations on the Labrador Current, the Expedition made a collection of the flowers and plants from the Torngat Mountains and explored several of the fiords which indent the northern part of the coast. Plankton-hauls and collections of the salmon, char, and cod were also made. Since very little oceanographic work had been done off the northern part of Labrador, the region proved most profitable for a short cruise.

In general, we will limit this discussion to the Labrador Current between the Strait of Belle Isle and Davis Strait, since south of the former is the province of the Ice Patrol and therefore well known, and north of the latter there seems to be no subsurface temperature and salinity observations, which are so necessary in the modern treatment of ocean-currents. Besides the work of the *Chance* there are surprisingly few other subsurface observations from this sector. The *Scotia* in 1913 made three stations in the region of our southern profile, two of these being over the continental shelf and therefore directly comparable. From this point north to Davis Strait the information is limited to a few surface-temperatures and many observations on ice-movements. In 1924, under the direction of Dr. Hjort, a section was run across the narrowest part of Davis Strait which gives a very good picture of both

the Labrador and West Greenland currents. Since this is the most northerly of the available profiles, it will be described first.

In spite of the fact that at any depth the water is about 3° colder on the western side of the Strait than it is on the eastern side, the isopicnals are caused to slant downward on nearing the Baffin Land shore by the low salinity of all the Labrador Current water. The temperature and salinity profiles show that the water to the west of that having dynamic cause for a southward movement is colder than 0° (except near the surface and below 200 meters) and much of it is less saline than 33.5 per thousand. In the center of the Strait the isopicnals in the upper stratum are forced upward by a core of North Atlantic water (with temperature of about 3.5° and a salinity of about 34.7 per thousand) lying along the outside slope of the Greenland coastal bank. This water acts as the density-wall between the Labrador and West Greenland currents and makes possible the dynamic urge which drives the one southward and the other northward. It will be noted that the gradient for both currents is only slight. Attempts at velocity-calculations are almost worthless since there are so few stations and these vary so much in depth. Yet it is evident that even at this northern point the Labrador Current is driven by the slant of the density-lines *in situ* and is not primarily an overflow of Arctic water. An interesting speculation arising from the profile is whether or not the West Greenland Current plus the land drainage into Baffin Bay does not supply enough water to account for that which is carried out of Davis Strait by the Labrador Current.

We must suppose that the current continues southward hugging the Baffin Land shore until it reaches Hudson Strait where it finds an opening to the left and urged by the rotational effect of the Earth some water undoubtely starts up the north side of the Strait. But in Hudson Strait conditions are very different from Davis Strait. There can be no central core of North Atlantic water to act as a density-wall between the lighter water along each shore since the narrow mouth of the Strait is blocked by the greater part of the Arctic Current which continues southward past it without entering. Therefore the current in Hudson Strait will not arise from gradients set up in the Strait itself, but will be dominated by the outflow of fairly fresh water from Hudson Bay. The importance of this great source of fresh water to the oceanographic conditions along the Labrador coast does not seem to have been enough emphasized. This outflow of water probably results from an actual raising of the surface of the water in Hudson Bay by the inflow of rivers and streams from the immense land-area which drains into it. Hudson Strait is also the first outlet to the right for the counter-clock-

wise coastal current which has been reported in the Bay itself. What Arctic water does round Resolution Island and starts into Hudson Strait meets then the outflow of water from Hudson Bay, mixes with it, and is probably mostly sooner or later carried out again around Cape Chidley, to continue south as the well-known Labrador Current.

Hudson Strait appears to be an ideal place for tidal mixing, for not only is the tidal range great (thirty feet on the Baffin Land shore) but very strong currents (four to five knots) are reported off Cape Chidley and Resolution Island. The water of Hudson Bay origin cannot differ much in character from the water of the Labrador Current with which it mixes in the mouth of Hudson Strait, for the temperature and salinity profiles made by the *Chance* just south of Cape Chidley shows water of the same character as on Dr. Hjort's profile of Davis Strait.

It is interesting from the temperature-profile of the waters of Nachvak Fiord that more than half of the water in the Fiord is half a degree colder than any of the Labrador Current. This would indicate a gradual warming up of the water over the continental shelf as the summer advances. The deeper waters of the Fiord, being motionless and protected from solar warming by a very stable surface-film of nearly fresh water, probably do not vary at all in temperature. From the mouth of the Fiord to the edge of the continental shelf is a distance of about ninety miles. This region is entirely covered by icy water. Off shore is the warmer water of North Atlantic origin and the most striking thing in this profile is the very abrupt temperature-transition which takes place between the two outer stations where in a distance of about fifteen miles the whole column of water increases about 5° in temperature.

The salinity-profile shows this same abrupt transition between the water of the Labrador Current and the homogeneous mass of the North Atlantic water just outside the edge of the continental shelf. Off the mouth of the Fiord is a region where the water has about the same salinity and temperature from top to bottom. This is probably water which has rounded Cape Chidley and which has been kept well mixed by the tidal current and waves over the many shoals and reefs just north of the profile. As in Davis Strait all the water of the Labrador Current has a salinity of less than 33.5 per thousand.

When we consider the density-profile, a puzzling fact is at once evident. The isopicnals are practically horizontal for the first sixty miles off shore, but outside of this is a narrow band where the dynamic gradient is most pronounced. Is the current confined to only this outer band as is indicated by the profile, or is all the water over the continental shelf moving south? From stations twenty-four miles apart there is a rise of 24.7 dynamic centimeters. This is enough to produce

a current of about one knot along the outer edge of the icy water. Yet while making this profile we noticed particularly that, although the majority of the bergs were well off shore, a noticeable current existed in the region where the isopicnals are perfectly horizontal. My only suggestion is that possibly the in-shore water gets its movement from the water which is forced out of Hudson Strait as a result of the immense land-drainage into Hudson Bay.

Continuing south again for the next three hundred miles, the Labrador Current flows along the continental shelf constantly mixing with the warmer more saline water along its outer edge, but maintaining its low salinity by the inflow of the many streams along the coast. The characteristic low temperatures persist since as the water flows southward the solar heat cannot penetrate by convection because of the great stability of the water-layers, and the light surface-film itself cannot warm appreciably because of the melting of the many bergs which the Current carries south. Thus we find the Labrador Current off Sandwich Bay nearly the same in volume and character as when it passes through Davis Strait.

The Sandwich Bay temperature-profile shows a much greater volume of water colder than $-1.5°$ than did the Nachvak profile. This is another indication that the Labrador Current as a whole warms up very slightly as the summer advances because the Sandwich Bay profile was made three weeks earlier in actual time than the Nachvak profile and we must add another four weeks more for the real time interval as at the rate of twelve miles a day it would take the water twenty-eight days to move southward the three hundred and thirty miles between the two sections. Right in-shore and near the surface is a narrow band of very much warmer water. This is the coastal stream always met with by boats sailing near the coast and it consists of the very fresh water which flows out of the many bays. Since this profile is just south of Hamilton Inlet, the comparatively warm coastal stream, really a current within a current, is particularly well developed. A conspicuous gulley in the center of the profile, filled with water $2.5°$ warmer than that above it, is something of which the few soundings on the chart gave no indication. It is not at all characteristic of the coast in general. Off-shore we notice a narrow band of icy water extending eastward between the depths of forty and one hundred meters, bulging outward the nearly vertical isotherms of the transition region between these depths. Bottom warming is another conspicuous feature of the profile. It is present wherever the water is more than one hundred and fifty meters in depth. The Labrador Current is so very light that it tends to spread out on the surface and when it passes over places that are deeper than two hundred

meters, warmer water is drawn in from off-shore and a slight mixing results.

The Sandwich Bay salinity-profile shows no important difference from the Nachvak profile except for the great freshness of the warm coastal stream the surface-waters of which have a salinity of less than 20 per thousand. But when salinities and temperatures are converted into densities a very different picture results. The slant of the isopicnals is continued across the whole profile and is not confined to a narrow band as off Nachvak. Thus all the water over the continental shelf, except in the bottom of the gulley, is being driven south by a moderate dynamic gradient and the current is distributed equally across the whole distance. Between two stations one hundred and eight miles apart there is a rise of 25.3 dynamic centimeters. This is almost exactly the same rise which was present off Nachvak in a distance of twenty-four miles.

This broadening and slackening of the gradient is well brought out by the horizontal projection of the dynamic forces. The five-dynamic-centimeter contours of only two sections make it, of course, impossible to represent with any certainty the course of the dynamic isobaths along the middle part of the coast. The possible course, however, of the strength of the Current may be based on observations on the distribution of bergs. These tended to be strung out in long rows well off-shore in the region off Nachvak and more scattered off Sandwich Bay. Along the middle part of the coast, especially near Cape Mokkovick and Cape Harrison, great numbers of bergs were aground close to the shore. On the other hand, the coast near Hamilton Inlet and also for the first one hundred and fifty miles south from Cape Chidley was comparatively free of ice.

Turning now to the velocity of the Current along the Labrador coast we find that a good average figure for the whole length of the coast is ten to fourteen miles a day. Off Nachvak, where as we have seen the gradient was steep over the edge of the continental shelf, velocity-calculations give as much as twenty-three miles a day for a narrow band, but down off Sandwich Bay velocity-calculations give at the most ten miles a day. In navigating I found that the Current was generally slightly stronger than this. The drift of the *Polaris* floe-party in March and April, 1873, averages fourteen miles a day from off Hudson Strait to a point off Hamilton Inlet where their daily average decreased to about eight miles a day until they were rescued. At this time of year the prevailing northwest winds probably accelerated their drift, while the Current itself was probably slightly slower than in summer for the main force which maintains the low density of the coastal water, that is land-drainage, had not yet come into full operation. We must expect a sea-

sonal fluctuation in the strength and volume of the Current depending on the liberation of great quantities of fresh water each spring all along the coast.

Finally, what is the state of the warmer, more saline, North Atlantic water outside the edge of the continental shelf? Is this moving south also as most current-charts for the North Atlantic indicate? Light is thrown on this question by a profile made by the *Scotia* in 1913 just south of the Strait of Belle Isle. This consists of six stations and extends about five hundred miles off-shore in a line roughly perpendicular to the general trend of the coast. When the densities for the profile are calculated and plotted, a most interesting fact is at once evident. Just off the edge of the continental shelf the isopicnals slant upward indicating a southerly current about one hundred miles wide, but for the next three hundred miles off-shore the isopicnals at all depths are perfectly flat showing that if the warmer, more saline, off-shore water was moving south at all, it was not through dynamic forces. There is no reason to think that this same condition does not exist further north where the *Chance* sections were too short to include the flattening out of the density-lines. The Labrador Current is then primarily an icy stream over the continental shelf which flows southward inside of the motionless homogeneous mass of North Atlantic water which is present along its outer edge even to a point north of Davis Strait.

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RECENT PROGRESS IN THE DYNAMICAL OCEANOGRAPHY OF THE NORTHEASTERN PART OF THE NORTH PACIFIC OCEAN

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INITIAL EXPLANATIONS OF COLD WATER OFF THE WEST COAST OF NORTH AMERICA

Numerous observations distributed through a period of many years have established the presence of abnormally cold surface-water contiguous to the Pacific Coast of North America. The results of several different attempts to account for this interesting phenomenon without the aid of an adequate dynamical basis have been published. Some of the conclusions thus reached are briefly reviewed here.

(1) The Japan Current in its slow and interrupted flow eastward is partly deflected to the south from Southern Alaska. It loses its heat as it flows southward and produces the fogs and rains in the region of Washington and Oregon. By the time it reaches San Francisco it is a cold current simply because it is intruding into a normally warmer area.